

NSWCCD-50-TR-2011/069

---

**Naval Surface Warfare Center**  
**Carderock Division**  
West Bethesda, MD 20817-5700

---

**NSWCCD-50-TR-2011/069 December 2011**

**Hydromechanics Department Report**

**Birth of U.S. Naval Aeronautics and the Navy's  
Aerodynamics Laboratory**

by

David J. Haas, Eric J. Silberg



# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 01-12-2011	2. REPORT TYPE Final	3. DATES COVERED (From - To) -		
4. TITLE AND SUBTITLE Birth of U.S. Naval Aeronautics and the Navy's Aerodynamics Laboratory		5a. CONTRACT NUMBER		
		5b. GRANT NUMBER		
		5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) David Haas, Eric Silberg		5d. PROJECT NUMBER		
		5e. TASK NUMBER		
		5f. WORK UNIT NUMBER 99-2-5300-010-12		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) Naval Surface Warfare Center Carderock Division 9500 MacArthur Boulevard West Bethesda, MD 20817-5700		8. PERFORMING ORGANIZATION REPORT NUMBER NSWCCD-50-TR-2011/069		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander Naval Surface Warfare Center Carderock Division 9500 MacArthur Boulevard West Bethesda, MD 20817-5700		10. SPONSOR/MONITOR'S ACRONYM(S)		
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution unlimited, approved for public release.				
13. SUPPLEMENTARY NOTES 20120322001				
14. ABSTRACT This report describes the formation of the Navy's Aerodynamics Laboratory and its pioneering contributions from 1911 to 1919. The Navy was just beginning serious interest in aviation in 1911 with the procurement of its first aircraft, the Curtiss A-1. This aircraft was similar to the Wright brothers' first airplane but with greater power to allow takeoff from the water. At this time there were no universities that offered education in aeronautical engineering nor were there any government aeronautics laboratories in the U.S. Aeronautical engineering was largely a process of trial and error. While this method worked for small aircraft like the A-1, it posed an impediment for development of more capable aircraft. Under the leadership of RADM David Taylor, the Navy's Experimental Wind Tunnel was built at the Washington Navy Yard next to the Experimental Model Basin to advance the state of aeronautical engineering. The new wind tunnel was the world's largest and the core of the Navy's Aerodynamics Laboratory. The laboratory developed methods for testing scaled models of complete aircraft as well as aircraft components. These experiments provided the data to design large aircraft and led to the success of the Navy's NC flying boat. The laboratory established a foundation for the development of aeronautics and left a legacy that continues 100 years later.				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF: a. REPORT UNCLASSIFIED		17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 25	19a. NAME OF RESPONSIBLE PERSON David Haas
b. ABSTRACT UNCLASSIFIED		19b. TELEPHONE NUMBER (include area code) 301-227-1397		
c. THIS PAGE UNCLASSIFIED				

This page intentionally left blank

## TABLE OF CONTENTS

ABSTRACT .....	1
ADMINISTRATIVE INFORMATION .....	1
INTRODUCTION .....	1
1911-1913: NAVY PROCURES ITS FIRST AIRPLANE AND ESTABLISHES THE FOUNDATION FOR AN "AERODYNAMICAL LABORATORY" .....	3
1914-1916: NAVY OPENS WORLD'S LARGEST WIND TUNNEL AND DESIGNS FIRST SEAPLANE.....	4
1917-1919: NAVAL AERONAUTICS MATURES, LEADS TO FIRST FLIGHT ACROSS ATLANTIC .....	8
THE LEGACY OF DAVID W. TAYLOR – 100 YEARS OF AERONAUTICS .....	12
ACKNOWLEDGMENTS.....	13
REFERENCES .....	15

## FIGURES

1. The Navy's first airplane, the Curtiss Model A-1.....	2
2. Test of Curtiss A-1 and Model F in the Experimental Model Basin .....	4
3. Navy's 8-foot by 8-foot Wind Tunnel under construction.....	4
4. Scaled model and schematic of Navy's first wind tunnel .....	5
5. Technician in Experimental Wind Tunnel.....	5
6. Vertical splitters and grid to adjust flow field in wind tunnel.....	5
7. Wind tunnel observation and control room.....	6
8. Force vectors displayed on schematic of Sturtevant S-4 model tested in 1916 .....	6
9. First Navy designed aircraft, the 82-A, in the wind tunnel (1915) .....	7
10. The 82-A undergoing testing on the Anacostia River at the Washington Navy Yard .....	7
11. First aircraft model tested in 1917, the B-class blimp .....	8
12. Seaplane models tested in early 1917 .....	8
13. Early design for the NC flying boat, 1917 .....	9
14. Schematic of an early configuration of the NC-1 .....	9
15. Giant 60,000 pound flying boat models tested in 1918 .....	10
16. HS-1 and H-12 flying boats tested in the Navy's wind tunnel .....	10
17. F-5-L flying boat model tested in 1919 .....	10
18. Model of rigid airship tested in 1918 .....	10
19. Various cars for airships evaluated in the wind tunnel .....	10
20. Control surfaces and airfoils tested in the wind tunnel from 1917 to 1919 .....	11
21. N-1 model tested in 1917, Navy's first attack aircraft.....	11
22. Full-sized functioning aircraft radiators evaluated in the wind tunnel .....	11
23. Air driven systems tested in wind tunnel (1918) .....	11
24. Unusual aircraft configuration tested in late 1918 .....	12
25. Tests of "passive airscrews of great resistance", 1917 .....	12
26. Model of the A-1 tested and the 8-foot by 10-foot subsonic wind tunnel at Carderock, 1961 .....	13
27. The Navy's large subsonic wing tunnel at Carderock .....	13

## TABLES

1. Summary of wind tunnel tests conducted at the Navy's Aerodynamics Laboratory from 1917 through 1919 .....	9
--	---

## ABSTRACT

This report describes the formation of the Navy's Aerodynamics Laboratory and its pioneering contributions in naval aeronautics from 1911 to 1919. The Navy was just beginning serious interest in aviation in 1911 with the procurement of its first aircraft, the Curtiss A-1. This aircraft was technologically similar to the Wright brothers' first airplane but with greater power to allow takeoff from the water using its large central float. At this time there were no universities that offered degrees, or even courses, in aeronautical engineering nor were there any government aeronautics laboratories in the United States. The practice of aeronautical engineering was largely a process of trial and error. While this method was successful for small aircraft like the A-1, it posed a significant impediment for development of larger more capable aircraft. Under the leadership of Rear Admiral David W. Taylor, the Navy's "Experimental Wind Tunnel" was designed and built at the Washington Navy Yard next to the Navy's Experimental Model Basin to advance the state of aeronautical engineering. The Navy's new wind tunnel was the world's largest and the centerpiece of the Navy's Aerodynamics Laboratory. The laboratory, and the naval constructors who worked there under Taylor, developed and refined methods for testing scaled models of complete aircraft as well as aircraft components. These experiments provided the data needed to effectively design large aircraft and led to the success of the Navy's NC flying boat. In 1919, an NC was the first airplane to fly across the Atlantic, just eight years after the Navy procured its first airplane. This was an accomplishment that at the time was as amazing to the average person as landing on the moon would be fifty years later. In a decade when U.S. advancements in aeronautics were waning, the pioneering work of the Navy's Aerodynamics Laboratory propelled the Navy to the forefront of aeronautics in the second decade of the 20<sup>th</sup> century. The laboratory established a foundation for the continued development of aeronautics and left a legacy that continues 100 years later.

## ADMINISTRATIVE INFORMATION

This work was conducted as part of the 2011 celebration of the Centennial Anniversary of Naval Aviation under work unit number 9-2-5300-010-12. It was presented as AIAA paper 2011-6943 at the Centennial of Naval Aviation Forum in Virginia Beach, Virginia, 21 – 22 September, 2011.

## INTRODUCTION

The U.S. Navy's early interest in Aviation was sparked by the 1896 success of Professor Samuel Langley's unmanned steam powered "aerodrome." Upon learning of the successful flights of the aerodrome, then Assistant Secretary of the Navy Theodore Roosevelt saw the potential applications for naval warfare. In 1898 Roosevelt established a board with Army and Navy representatives to make recommendations with regard to the practicality of a full sized manned flying machine and supporting continued experimentation and development by Professor Langley.<sup>1</sup> Despite the board's favorable recommendations, it would be another ten years before the Navy would seriously consider the potential of the airplane for naval warfare. In the intervening years the Wrights would capture the world's attention by being the first to demonstrate controlled powered flight. However, this achievement started to dim by the end of the first decade of the 20<sup>th</sup> century as European advances in aeronautics took place.

In September of 1908 the Wrights demonstrated their flying machine to Army and Navy observers at Fort Myer, Virginia, across the Potomac River from Washington, D.C. The Navy observers present were Lieutenants William McEntee and George Sweet. Although the demonstration turned tragic due to an accident that killed Army Lt. Thomas Sulfridge, a passenger, the Navy's interest in aviation was re-ignited. Flight demonstrations continued in 1910 and 1911 with the first take-off and landing both from a ship and from the water. The Navy embarked on a future with aviation in May of 1911 when the first order for two aircraft from the Curtiss Aircraft Company was placed, thus marking the birth of naval aviation.<sup>2</sup> Although French aviator Henri Fabre was the first to fly from the water, the Navy's A-1 "hydroplane" of 1911 developed by Glenn Curtiss was the first truly successful seaplane (Fig. 1). From this humble starting point in 1911, the Navy would capture the world's attention by the end of the second decade of the 20<sup>th</sup> century and become the foremost developer of large flying boats.

To support the scientific development of naval aeronautics, the Navy turned to the Experimental Model Basin (EMB) at the Washington Navy Yard. The EMB was established in 1898 by then CDR Taylor<sup>3,4</sup> for conducting scientific experiments related to ship hydrodynamics and naval architecture. It operated under the auspices of the Navy's Bureau of Construction and Repair and was a world class experimental facility that helped establish the Navy's expertise in hydro- and fluid dynamics. LT McEntee, who earlier observed the Wrights' demonstration at Fort Myer, worked at the EMB and was an aviation enthusiast as was his supervisor, then CAPT Taylor, who was in charge of the EMB. Taylor and his staff began initial investigations of naval aircraft in 1911 using the EMB facilities for hydrodynamic experiments of seaplane floats and flying boat hulls, as well as for aerodynamic investigations.<sup>5</sup>

David Taylor was a distinguished naval architect and widely respected researcher with extensive experience in hydrodynamic testing of ships. Just as he had done for naval architecture earlier, Taylor recognized the need for scientific facilities to advance the field of aeronautics and he went on to develop the world's largest wind tunnel. By 1914 the Navy had the two key facilities critical to becoming the world's leader in the design of large flying boats; the Experimental Model Basin to measure hydrodynamic forces on the hull and the Experimental Wind Tunnel (EWT) to measure aerodynamic forces on the aircraft. With these facilities, aircraft design could advance from an art of trial and error based on experience (as was the case in 1911) to the engineering science of aeronautics (as would be needed for the design of the NC flying boat). Using these experimental facilities over the course of just a few short years, the Navy would design and build a flying boat larger than any before that would be the first to fly across the Atlantic.<sup>6,7</sup> The pioneering work of David Taylor and his colleagues at the Navy's Aerodynamics Laboratory propelled the Navy to the forefront of aeronautics by 1919. It would not be until the early 1920's when the National Advisory Committee for Aeronautics (NACA) began operations of their first wind tunnel before another laboratory in the United States would rival that of the Navy's.

The focus of this paper is on the early years of the Navy's Aerodynamics Laboratory from 1911 to 1919. This period is significant because aeronautics in the Navy came of age at a time when there were no aeronautical engineering curricula taught at any university in the United States. In addition, very rapid progress in naval seaplane development took place between 1911 and 1919, starting from the 1500 pound A-1 hydroplane procured in May 1911 and culminating with the 28,000 pound NC flying boat that crossed the Atlantic Ocean in May of 1919. The development of the NC flying boat was no small feat; a large flying boat is far more complex to design than a land based aircraft, as it must perform the functions of two vehicles in one, a fully sea worthy boat capable of surviving rough seas and an aircraft capable of long missions with significant payloads.

In preparing this paper, the authors, who are aerospace engineers at the Navy's David Taylor Model Basin located at the Carderock Division of the Naval Surface Warfare Center, reviewed over 150 original wind tunnel reports from the Navy's Aerodynamics Laboratory and inspected many of the actual models that were tested. RADM Taylor's personal collection of papers and memorandums were also examined, as well as early photographs involving tests at the Navy's Aerodynamics Laboratory.

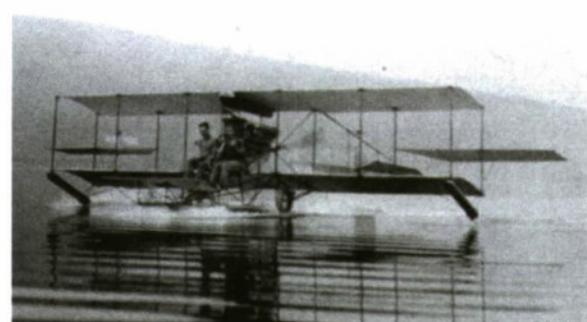


Figure 1. The Navy's first airplane, the Curtiss Model A-1.

The development of naval aeronautics from 1911 through 1919 is presented in three parts. The first part spans from 1911 to 1913 when the Navy procured its first aircraft and established the foundations of the Navy's "Aerodynamical" Laboratory, as it was originally referred. During this time, the Navy utilized the Experimental Model Basin to evaluate seaplane floats and measure forces on airplane wings. The second part focuses on the period from 1914 to 1916 when the Navy opened its Experimental Wind Tunnel and utilized it to develop the first Navy designed aircraft. The third part spans from 1917 to 1919 and describes the Aerodynamics Laboratory's support for the war effort and the development of the NC flying boat, including a comprehensive review of the many types of tests conducted in the Navy's Experimental Wind Tunnel.

### **1911-1913: NAVY PROCURES ITS FIRST AIRPLANE AND ESTABLISHES THE FOUNDATION FOR AN "AERODYNAMICAL LABORATORY"**

To be truly useful to the Navy, aircraft needed to be capable of operating from the sea. This requirement added significant technical challenges to the design. In addition to determining lift and drag of the wings and control surfaces, knowledge of the hydrodynamic lift and drag of the hull or floats at high speed was needed. Despite previous failed attempts in 1908 to design a seaplane, Glenn Curtiss once again concentrated his efforts on development of a "hydro-aeroplane" in 1910.<sup>8</sup> His earlier attempts were unsuccessful due largely to a combination of power limitations of engines of that time and the high drag and suction forces of early seaplane floats. In 1911, Glenn Curtiss delivered the first successful hydro-aeroplane (or hydroplane) to the Navy. This aircraft was designated the Model A-1. Later that year the first Naval Air Station was established at Annapolis, Maryland for aircraft experimentation and flight training. In 1912, Curtiss redesigned the center float of his seaplane into a strengthened and enlarged hull and delivered the first successful flying boat to the Navy designated Model AB-1. The flying boat concept would prove to be so useful to naval aviation that it would provide utility in naval operations for half a century.

In 1911, under the direction of then CAPT Taylor, the EMB at the Washington Navy Yard was well established as a preeminent scientific test facility for the study of hydrodynamic forces on ships. With the delivery and evaluation of the A-1 hydroplane, Taylor realized that the Navy would need an equivalent facility for the study of aerodynamic forces on aircraft. Taylor obtained authorization to begin aeronautical investigations at the EMB and initiated efforts to design and build the Experimental Wind Tunnel to serve the same purpose for aircraft as his EMB did for ships starting some thirteen years earlier. To improve the poor hydrodynamic performance of early seaplane floats, Taylor utilized the expertise and facilities at the EMB.<sup>5</sup> A systematic set of float tests were initiated at the EMB in 1911 and continued into 1912. Various types of float configurations were investigated, including wing section floats, sled-type box floats, canoe shaped floats, as well as single and twin floats with various step configurations and V-bottoms. These basin tests were of great value, providing data on hull resistance at different trim points, planing capacity, righting moments at rest, tendency of porpoising, and spray patterns.<sup>9</sup> During this time frame, tests to measure lift and drag on wings was also undertaken in the EMB. Review of early logs of EMB models show that tests were conducted on pontoon floats for the Wright, Curtiss, and Burgess-Wright seaplanes, as well as many others. In 1913, numerous tests of flying boat hulls were conducted, including designs from Curtiss and Burgess. Indeed, the EMB proved to be an invaluable tool in the development of the Navy's seaplanes and flying boats.

Figure 2 shows a model of the Curtiss A-1 and an early Model-F type flying boat undergoing tests at the EMB. The basin tests were conducted by LT William McEntee, later joined by LT Holden Richardson, both of whom were naval constructors and assistants to David Taylor. These experiments helped to quantify the benefits of adding a step in the float to reduce the speed where the hull planes on the water at reduced drag, thereby increasing takeoff performance of early seaplanes significantly. A critical challenge in the design of seaplanes is to determine the proper relationship between the planning surface of the hull and the angle of incidence of the wings to ensure a smooth transition from hydrodynamic lift produced by the hull and aerodynamic lift produced by the wings. A successful configuration will provide sufficient speed at takeoff to ensure adequate aerodynamic control and efficient cruise in the air within the power limitations of the engine.

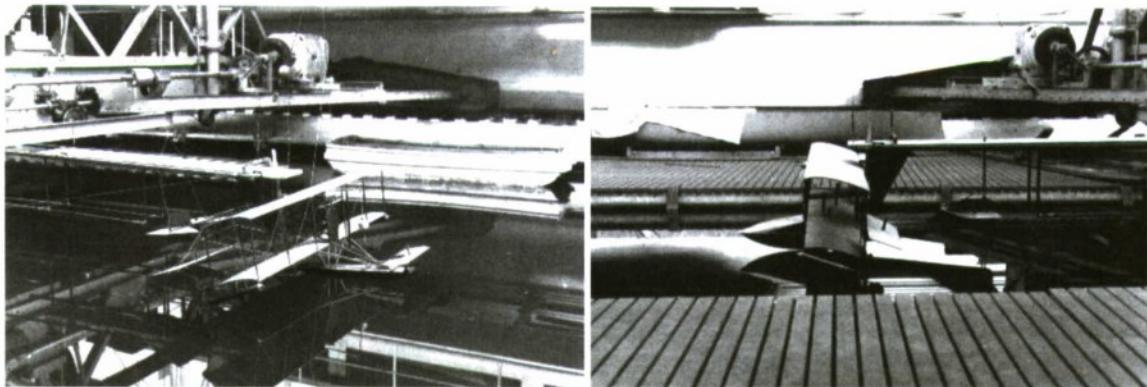


Figure 2. Test of Curtiss A-1 (left) and Model F (right) in the Experimental Model Basin.

Along with testing seaplane floats and hulls in 1912, Richardson studied the pioneering wind tunnel research of French architect Gustave Eiffel from Eiffel's 1911 book, *The Resistance of the Air and Aviation*, and he, Taylor, and McEntee began design of a suitable wind tunnel facility for the Navy's work in aeronautics and aircraft development.<sup>10</sup> In 1913, funds were appropriated for the construction of what would be the world's largest wind tunnel. Construction of the tunnel and a building to house it began at the Washington Navy Yard that same year (Fig. 3). At this period in time, the use of large wind tunnels to evaluate complete aircraft designs was virtually nonexistent. Realizing the importance of developing aeronautics as a field of study, the Navy sent Lieutenant Jerome Hunsaker to MIT for graduate studies, to develop a course in aeronautics (the first in the country), and to design experiments for aircraft. Hunsaker built a wind tunnel at MIT for experimentation with a 4-foot square test section similar to that used at the National Physical Laboratory in England. Hunsaker completed his PhD at MIT in 1916 and returned as a naval constructor to play an important role in the design of the NC flying boat. The summer of 1913 brought both accomplishment and tragedy; an altitude record of 6200 feet was established in a Model A-2 and the first naval aviation fatality occurred on June 20.

#### 1914-1916: NAVY OPENS WORLD'S LARGEST WIND TUNNEL AND DESIGNS FIRST SEAPLANE

In 1914 the first training facility for naval aviators was established in Pensacola, Florida. In the same year, the wind tunnel at the Washington Navy Yard was completed and the Navy's Aerodynamics Laboratory officially opened. Also, in 1914 David Taylor was promoted to rear admiral and appointed Chief Constructor of the Navy in charge of the Bureau of Construction and Repair. The Experimental Model Basin and the Aerodynamics Laboratory were both under this bureau. Taylor appointed CDR McEntee director of the newly established Aerodynamics Laboratory. The Experimental Wind Tunnel at the Laboratory featured a closed circuit design with a test section (or experimental chamber as it was called then) measuring 8-feet by 8-feet, the largest in the world (Figs. 4, 5). It was constructed entirely of wood with frames spaced about three feet apart on the outside of the circuit and sheathed on the inside with 7/8<sup>th</sup> inch tongued-and-grooved

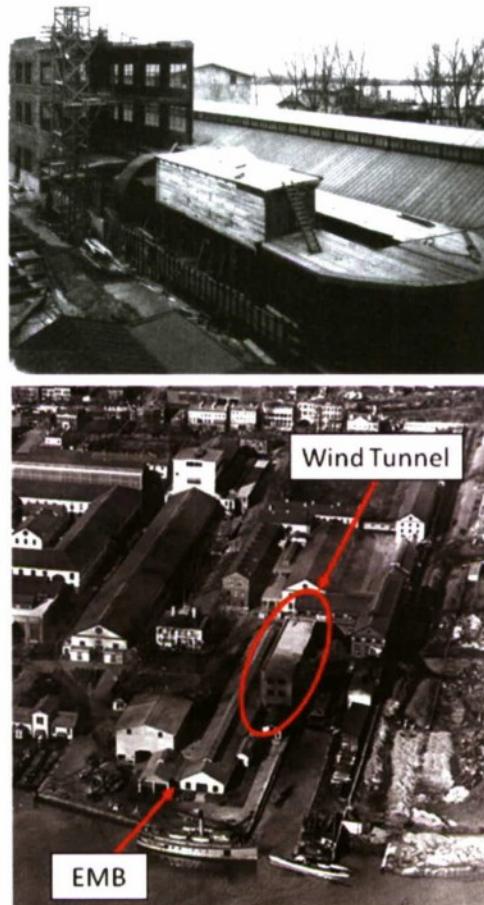


Figure 3. Navy's 8-foot by 8-foot Wind Tunnel under construction at the Washington Navy Yard (top), and the completed Aerodynamics Laboratory building (bottom).

sheathing. The fan blower was a paddle type with a top-horizonal discharge duct measuring 7.5 feet by 9 feet and an inlet diameter of 11 feet 2 inches. It was powered by a 250 volt, 500 horsepower direct drive motor.<sup>11</sup>

The tunnel was run for the first time in March 1914 and underwent a period of calibration in the latter part of the year. For validation of the new tunnel, measurements were compared to those obtained from tests conducted in the smaller wind tunnel at MIT and with experiments conducted in the wind tunnel at the National Physical Laboratory in England. Tests of wings used in Eiffel's experiments were also conducted as a preliminary check of tunnel accuracy.<sup>12</sup> A honeycomb grid of 64 one-foot square ducts eight feet long (in the direction of flow) was installed ahead of the test section and three intermediate vertical "splitters" were installed in the return<sup>10,11</sup> (Fig. 6). These ducts and splitters could be adjusted to enhance flow quality. Each cell of the honeycomb grid had a damper in order to control the velocity of air such that at the position of the model in the test section the maximum variation from the uniform flow was about two percent.<sup>11</sup> Normal test speed was forty miles per hour, with a maximum of seventy five. At the discharge side of the fan were located twelve pitot tubes which led to an integrating manometer measuring the average discharge velocity. This velocity was calibrated against the velocity in the test section and used as a means of setting the test speed without introducing pitot tubes into the test section. The pitot tubes were checked with those used at the aerodynamics laboratory at MIT and at the National Physical Laboratory. A series of vent holes was located in the tunnel walls just down stream of the test section. These holes served the dual purpose of introducing fresh cool air and maintaining the gradient of pressure in the test section.

To measure force and moment data, the model was mounted on a steel spindle extending through the top of the tunnel to an Eiffel type balance that measured lift, drag (or "drift" as it was called), and pitching moment. In addition to the Eiffel balance, a special torsion balance was designed to provide a more accurate measurement of pitching

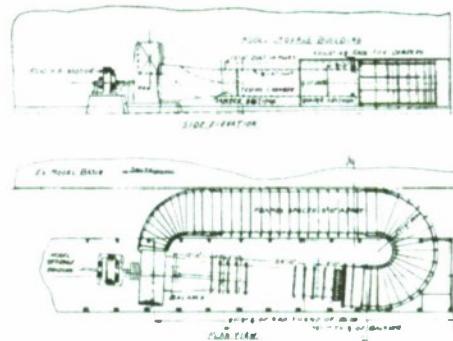
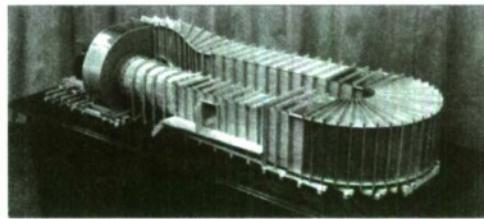


Figure 4. Scaled model (top) and Schematic (bottom) of Navy's first wind tunnel.



Figure 5. Technician in Experimental Wind Tunnel

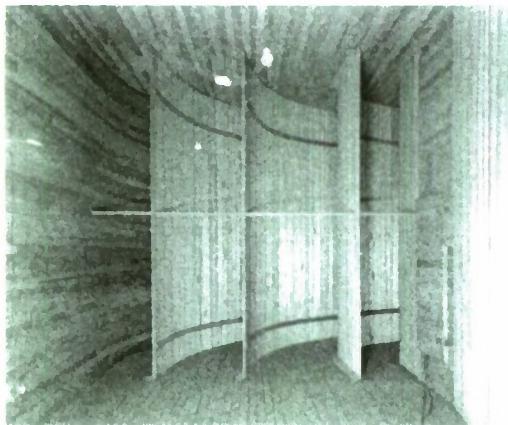
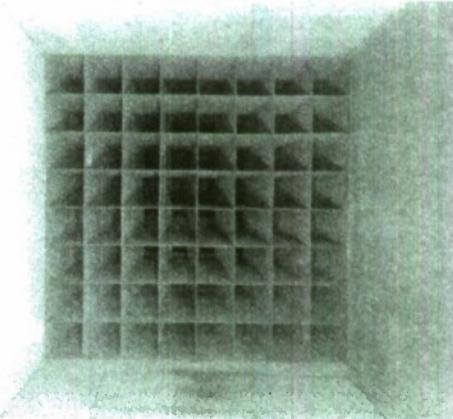


Figure 6. Vertical splitters (left) and 8-foot by 8-foot grid (right) were used to adjust the flow field.



moments. By changing the orientation of the model, the torsion balance could measure yaw or roll moments. Because of the large size of the test section, complete aircraft models with a wing span of three feet or more could be tested. At the typical test speed of 40 miles per hour, drag forces as low as 1/10 of a pound needed to be measured accurately requiring a balance accuracy of 2/1000 of a pound.<sup>11</sup> A bifilar wind balance, where the model is attached by thin steel wires, was also utilized to test airship hulls, struts, and airfoils providing uniform and consistent measurements of resistance. Later, in June of 1920, a full six-component balance designed and built by the laboratory was installed. This balance allowed the collection of all six forces and moments on the model at once and reduced the time to collect data for a typical sweep of sixteen model incidence settings at a given airspeed from eight hours to less and half an hour. These balances were installed directly above the test section in the observation and control room (Fig. 7).

Numerous tests were conducted in the early years of operation. Complete airplane models were tested, including designs that were already in use and others still under development. Other investigations conducted in the wind tunnel during this period include determining the coefficient of air friction for various airplane and balloon fabrics, aerodynamic forces on a dirigible building, as well as tests for a number of private concerns.<sup>11</sup> The large size of the tunnel even made it possible to test full-sized radiators for airplane motors both for air resistance and cooling capacity in a comparative manner. Non-aeronautical tests were also conducted. In fact, the first test in the tunnel examined the effect of varying dimensions of ships' ventilation cowling.<sup>11,12</sup> These tests indicated that many of the contemporary designs were larger than necessary, taking up valuable space in the confines of a ship.

By 1916, standard wind tunnel tests had been developed to analyze the lift, drag, performance, and stability of complete aircraft. Data collected during these tests were compiled in the form of plots of lift, drag, and lift-to-drag ratio versus angle of attack. The maximum and minimum speeds were also estimated from the measured drag using an assumed engine power and propeller efficiency. In addition, a series of resultant force vectors corresponding to each angle of attack measured was presented on a schematic of the airplane model (Fig. 8). This early data presentation method provided the means to quickly assess the aerodynamic performance, trim, control effectiveness, and longitudinal stability characteristics of the aircraft configuration under study. The slope of a vector relative to the free stream velocity indicates the lift-to-drag ratio, the location of a vector relative to the aircraft center of gravity indicates the trim state, and

the movement of the vectors as the angle of attack changes indicates if the aircraft is statically stable. Longitudinal control effectiveness could be assessed by observing how far the vectors moved fore or aft with different angles of elevator incidence.

Although a compete account of models tested before 1917 in the EWT is not available, it is estimated that 100 models were tested in the wind tunnel from mid-1914 through 1916 based on existing documentation of wind tunnel model numbers. Several

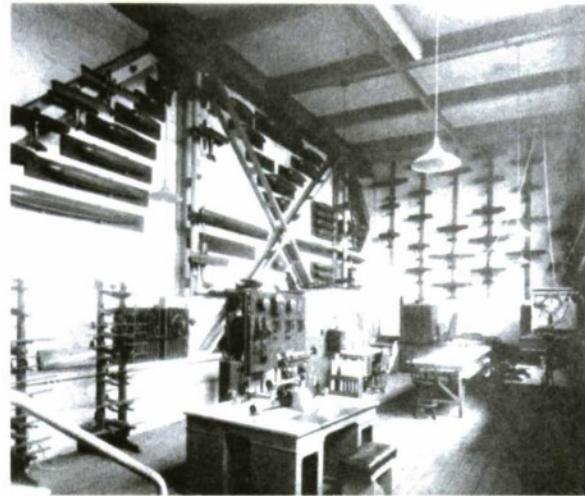


Figure 7. Wind tunnel observation and control room.

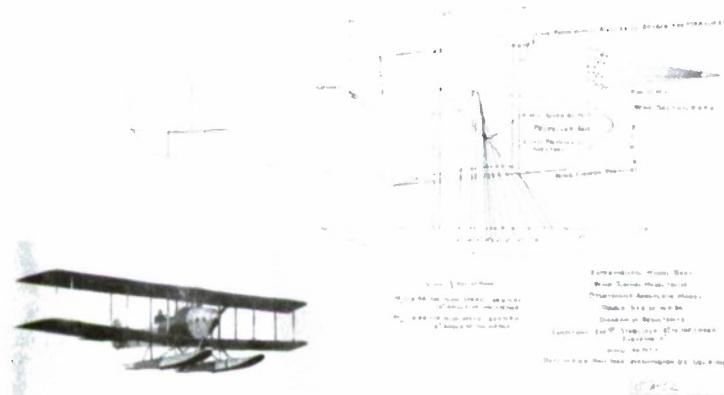


Figure 8. Force vectors displayed on schematic of Sturtevant S-4 model as tested in 1916.

wind tunnel models of the Sturtevant S-4 seaplane trainer (Fig. 8) were tested in late 1916 and early 1917. Initially a small S-4 model was tested in the 4-foot tunnel at MIT at 30 miles per hour. This model was then tested in the 8-foot tunnel at the Washington Navy Yard for comparison (but at 40 and 50 miles per hour and extrapolated to 30 miles per hour). In December, a 36 inch wingspan "double size" model of the same vehicle was also tested in the EWT to compare with the same ratio of model-size to tunnel-size.\* This model was labeled wind tunnel model number 114. Models tested in the Washington Navy Yard in 1917 began with wind tunnel model number 115 and increased thereafter.

With war in Europe underway and realizing the limited performance and quality of seaplanes available from airplane manufacturers in 1914, the Navy initiated design of its own seaplane at the Aerodynamics Laboratory under Richardson's lead. The aircraft, designated the 82-A, was the first aircraft designed and built entirely by the Navy, or any U.S. government agency. It was a large aircraft for its time. Weighing 6000 pounds and with three seats, it was also one of the earliest twin-engine seaplanes. In the summer of 1915, Richardson conducted tests of the 82-A float system, which included a large center float and smaller wing floats, in the EMB. In December of that year, he evaluated the performance of the design in the EWT (Fig. 9). The aircraft was built at the Washington Navy Yard and underwent flight testing on the Anacostia River in 1916 with Richardson (who was designated Naval Aviator No. 13 and was the Navy's first engineering test pilot) in charge (Fig. 10). Although the 82-A, which was also known as the Richardson Seaplane, never went into production, it signified the coming of age of the Navy's Aerodynamics Laboratory. The Navy's new wind tunnel was described to the general public in a 1917 article in Popular Science with the title, "Testing Airplanes in a Man-Made Storm" and showed a model of the 82-A as well as a ship model in the wind tunnel.

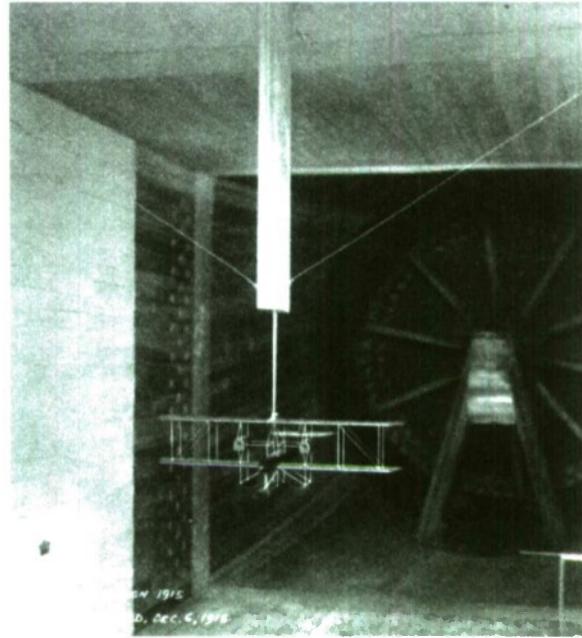


Figure 9. First Navy designed aircraft, the 82-A, in the wind tunnel at the EMB (1915).



Figure 10. The 82-A undergoing testing on the Anacostia River and at the Washington Navy Yard.

\* The Aeronautical Report for this test notes that the lift to drag ratio was higher for the larger model tested at higher airspeed in the EWT. These results are consistent with what would be expected based on Reynolds number scaling effects, although model scale effects were not fully understood in 1916.

## 1917-1919: NAVAL AERONAUTICS MATURES, LEADS TO FIRST FLIGHT ACROSS ATLANTIC

On April 11, 1917, when the United States entered World War I, the Navy's inventory of aircraft included forty-five seaplanes, six flying boats, and one airship. The need for developing and fielding capable seaplanes was more urgent than ever. By this time the pace of testing at the Aerodynamics Laboratory was substantial and the wind tunnel was operating 16 hours per day. Chief Constructor Taylor hired Dr. Albert F. Zahm to direct the Laboratory in January of 1917. Zahm was a long-time acquaintance of Taylor and in his scholarly work, even expressed his indebtedness to Taylor for suggesting the topic of his 1903 research on the measurement of air velocity and pressure.<sup>13</sup> Dr. Zahm was a well known pioneer in the field of aeronautics by this time and no stranger to the wind tunnel. In 1901, as a professor of mechanics at Catholic University, Dr. Zahm built an aerodynamics laboratory with a wind tunnel that had a large 6-foot square test section. This tunnel remained in operation until 1908. Later, working for Glenn Curtiss, he designed seaplanes as well as the wind tunnel balance for the their 4-foot by 4-foot wind tunnel and advanced to the position of Chief Research Engineer for the Curtiss Airplane Company.

A methodical researcher and true aeronautical engineer, Dr. Zahm instituted a discipline of formally documenting wind tunnel test setups and data collected in Aeronautical Reports issued by the Laboratory. One hundred forty nine Aeronautical Reports were written between 1917 and 1919 describing many types of tests and documenting the data collected. Once in charge of the Laboratory, Dr. Zahm wasted no time getting to work and the first three Aeronautical Reports were issued in January 1917. The second of these reports described a wind tunnel test on the "Resistance and Controllability of School Dirigibles" which included a photograph of the airship model (Fig. 11) identifying it as wind tunnel model number 115. This model corresponds to an airship designed by LT Hunsaker that became the Navy's first successful airship, the B-class blimp. The Navy procured sixteen B-class blimps for patrol service along the coast. The airship had a displacement of 77,000 ft<sup>3</sup>, a speed of 45 miles per hour, and a payload of 2000 pounds.

Due to the large size and flexible nature of the tunnel design, many types of tests were conducted between 1917 and 1919. In addition to models of complete seaplanes and airships, aerofoils (as they were called at that time), control surfaces, aircraft fuselages, airship cars, and seaplane hulls and floats were evaluated as well as miscellaneous models including bombs, parachutes, aircraft and wind tunnel instruments, wind driven accessories, cables and struts, and even ships. Table 1 summarizes testing in the Aerodynamics Laboratory for this three year period as well as for each individual year to provide insight into the types and numbers of tests that were important to the Navy at that time. Approximately fifty Aeronautical Reports were written each year. Although the vast majority of these reports correspond directly to wind tunnel tests, some were devoted to descriptions of wind tunnel instruments, analytical methods of data reduction, or hydrostatic tests of airship models filled with water.

As seen in Table 1, the most frequently occurring tests were of complete aircraft. In early 1917, numerous speed scouts, trainers, and other small seaplanes were tested including the Curtiss N-9, one of the most popular trainers in World War I (Fig. 12). Large flying boats with long range and high endurance were of great interest to the Navy to patrol the waters off the coast of Europe for U-boats without the need for a ship tender. In 1918, various configurations of large flying boats, including the initial design of the

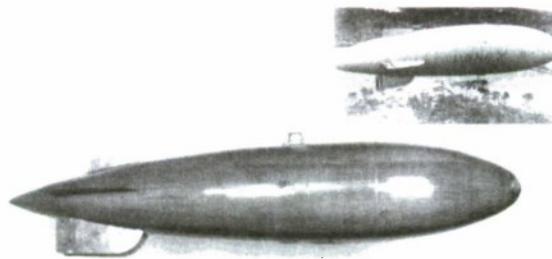


Figure 11. The first aircraft model tested in 1917 was this B-class blimp model, the Navy's first successful airship of which 16 were built for coastal patrol.



Figure 12. Numerous tests of small seaplanes including these speed scouts and trainers took place in early 1917.

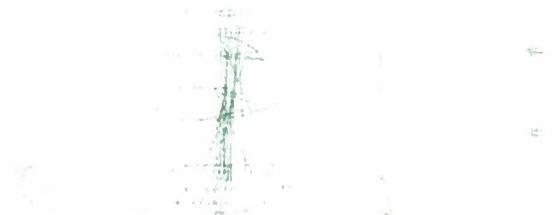
famous NC flying boat, were evaluated. Figure 13 shows a wind tunnel model of a "1000 hp seaplane", an early configuration of the NC flying boat, that was tested in November of 1917. This design evolved into the NC-1 configuration after modifications guided by both wind tunnel and model basin tests. The NC-1 configuration was tested in the wind tunnel in January of 1918 (Fig. 14). The hull of the NC flying boat with several stern variations was also tested in the wind tunnel in March of 1918 and in the model basin to optimize its shape for both hydrodynamic and aerodynamic efficiency. The NC-1 configuration (with observer station located on top of the upper wing as shown in Fig. 14) was first flown on October 4, 1918. During 1918 and 1919, flying boats even larger than the NCs were tested. Figure 15 shows two giant 60,000 pound flying boats that were tested in the latter part of 1918. Other significant flying boats that were tested in the wind tunnel include models of the HS-1 (6,000 lb class) and H-12 (10,000 lb class) in 1917 and the F-5-L (13,000 lb class) in 1919 (Figs. 16, 17). The model of the F-5-L was one of the largest airplane models tested, with a wing span of fifty two inches. The capabilities of the flying boat were so significant to naval aviation that by November of 1918 there were over 1,100 in the navy inventory. The year 1917 saw the greatest number of airplane designs tested. Review of the individual test reports indicates that in the earlier part of 1917 most tests were of smaller aircraft types whereas the latter part of the year involved testing of larger flying boats. This coincides with a 1917 directive issued by RADM Taylor to develop a self deployable aircraft to combat the German U-boat menace. He assigned Hunsaker and Richardson the task of making the concept a reality. To accomplish Taylor's vision, the Navy worked with Glenn Curtiss to design, build, and ultimately fly the first aircraft across the Atlantic, the NC-4 flying boat.

**Table 1. Summary of wind tunnel tests conducted at the Navy's Aeronautical Laboratory from 1917 through 1919.**

Aeronautical Reports and Type of Test	1917	1918	1919	Total
Aerodynamics Laboratory Reports	54	46	49	149
Wind Tunnel Tests Conducted	48	41	46	135
Complete Airplanes	22	11	6	39
Airships (Blimps, Dirigibles)	3	3	12	18
Aerofoils	6	4	3	13
Control Surfaces	2	1	2	5
Isolated Fuselage, Float/Hull, Airship Carriage	4	4	3	11
Aircraft Radiators	1	5	1	7
Wind Driven Devices and Air Screws	1	5	0	6
Instrumentation Tests and Calibrations	7	7	9	23
Bombs	1	0	1	2
Ship Airwakes	0	0	1	1
Ship Wind Deflector and Ventilators	1	0	2	3
Parachutes	0	0	1	1
Aircraft Cables and Struts	0	1	5	6



**Figure 13.** The design concept that later became the NC flying boat was first tested in November of 1917.



**Figure 14.** An early configuration of the NC-1 as well as several hull forms were tested in early 1918.

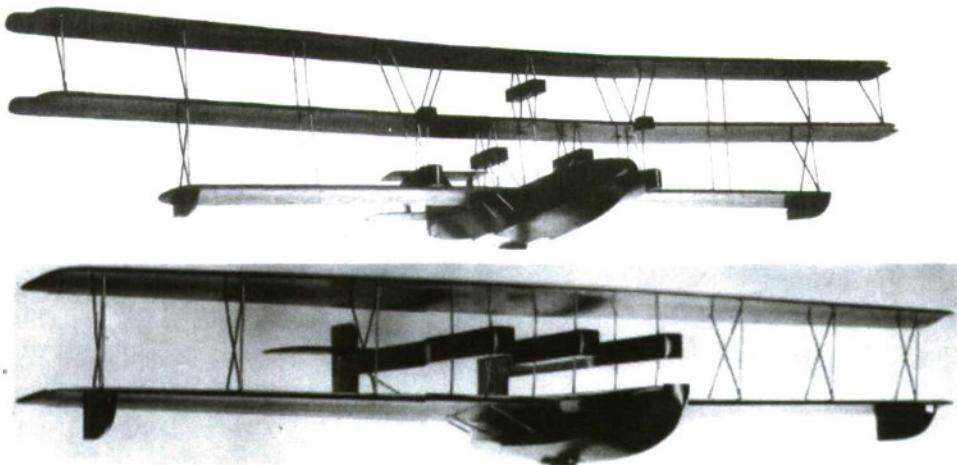


Figure 15. Tests of giant 60,000 pound flying boats took place beginning in the latter part of 1918.



Figure 16. Most of the Navy's flying boats were tested in the Navy's wind tunnel including the HS-1 (top) and H-12 (bottom) aircraft.

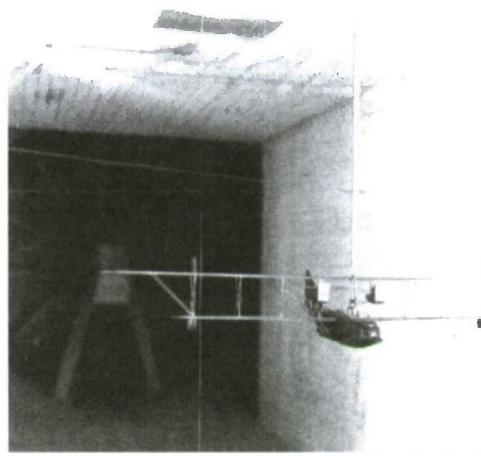


Figure 17. This model of the F-5-L flying boat was tested in 1919 and was one of the largest airplane models tested with a wingspan of 52 inches.



Figure 18. Model of rigid airship tested in 1918.

Figure 18 shows a 1918 model of a rigid airship designed and tested by the Aerodynamics Laboratory. In late 1918, the Navy requested funding for four large Zeppelin-type rigid airships. Table 1 shows that testing of airships was somewhat modest in 1917 and 1918, but consumed a significant amount of test time in 1919. In 1919, twelve separate tests of airship models were conducted and two additional tests were conducted on various airship "cars" (Fig. 19). Despite the emphasis of testing complete aircraft models to

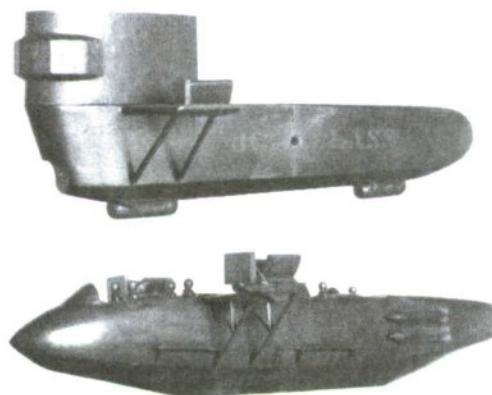


Figure 19. Various cars for airships were also evaluated in the wind tunnel.

evaluate overall performance of a specific design, there were also a significant number of tests devoted to basic airfoil characteristics. Some of these tests evaluated new airfoils developed by the Navy against the existing RAF-6 airfoil, a standard airfoil of the time. In addition to standardized tests of complete aircraft, standardized tests and model sizes were established for airfoils to measure lift, drag, and the center of pressure. In a 1917 test of various airfoils, a twenty-hole manometer was utilized to measure the pressure distribution on the upper and lower surfaces of the airfoil. Comparison of test results with those obtained from other smaller wind tunnel facilities was conducted to gain insight into the effects of model and test section size. Airfoils were tested in two standard sizes, 30 inches by 5 inches and 48 inches by 8 inches, the smaller size also having been tested in smaller 4-foot wind tunnels. Figure 20 shows an airfoil-like model of a control surface as tested in the wind tunnel and a photograph of the "aerofoil cabinet" in the Aerodynamics Laboratory in 1922.

In 1918, to lessen the demand on the 8-foot by 8-foot tunnel, the Aerodynamics Laboratory built a smaller 4-foot by 4-foot flow-through wind tunnel similar to those at MIT and the National Physical Laboratory. In addition, to broaden the speed range of the EWT, a special insert was designed to reduce the size of the test section to 8-feet by 4-feet, thereby increasing the maximum test speed to 120 miles per hour. Also in 1918, the Aerodynamics Laboratory tested a model of the N-1. The N-1 seaplane was the Navy's first attack aircraft and included a large Davis Gun mounted at the nose (Fig. 21). This aircraft was designed and built entirely by the Navy and was one of the first airplanes built at Philadelphia's newly established Naval Aircraft Factory in 1918.

Full-sized aircraft components continued to be tested. Figure 22 shows a functioning aircraft radiator, along with part of the aircraft fuselage, installed in the EWT. This was tested for its cooling capability as well as its aerodynamic characteristics. Air driven systems such as the fuel pumps on the F-5-L were tested in 1918 (Fig. 23). A number of unique looking and unusual airplane configurations were tested in the wind

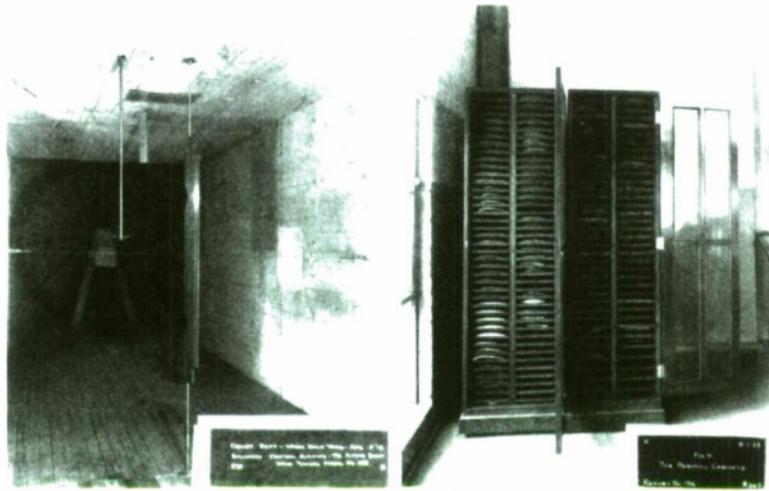


Figure 20. Control surfaces (left) and airfoils were tested in the wind tunnel from 1917 to 1919, a number of which can be seen in the "aerofoil cabinet" (right).

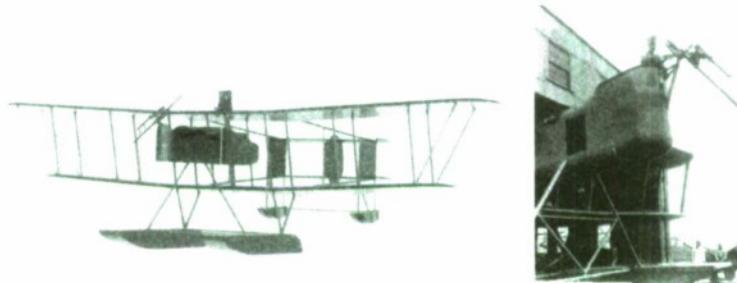


Figure 21. A model of the N-1 was tested in 1917; this seaplane was Navy's first attack aircraft.

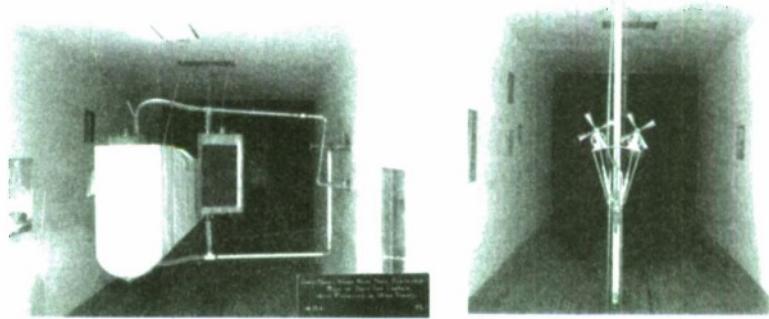


Figure 22. Full-sized functioning aircraft radiators were evaluated in the wind tunnel for cooling efficiency and drag, some included portions of the fuselage as seen here.

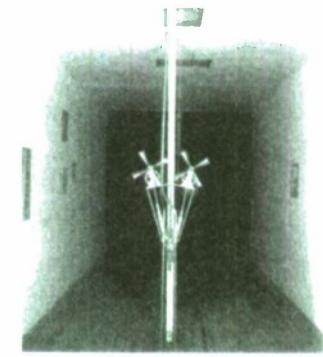
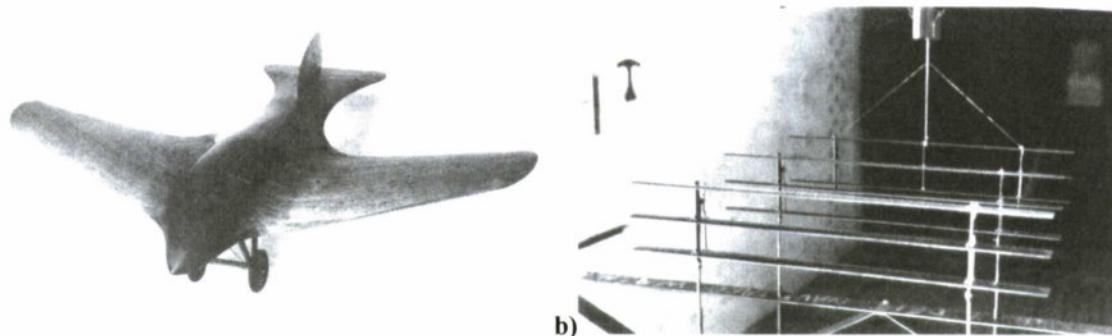


Figure 23. Air driven systems such as these fuel pumps on the H-12 flying boat were tested in the wind tunnel (1918).



a)

b)

Figure 24. Some of the more unusual aircraft configurations tested include a monoplane (a) and tandem triplane (b) both tested in late 1918.

tunnel or evaluated by the Laboratory staff. Figure 24(a) shows a futuristic monoplane model that was evaluated in the wind tunnel. This model had a surprisingly large lift to drag ratio despite its substantial undercarriage. Figure 24(b) shows a “tandem triplane” model that was also tested in late 1918. Although rotary wing aircraft were far behind in development compared with fixed wing aircraft, two early Aeronautical Reports addressed this topic. One involved a technical review of a proposed 1918 “hovering aeroplane” concept. No wind tunnel test was conducted, but the report concluded, “It is believed that, with present light motors of great power, a suitably designed aeroplane can be made to rise vertically from rest, hover stationary in still air, glide safely with passive motor or settle vertically to earth with active motor.” It was recommended that “at an opportune time some elementary experiments be made at the Naval Yard Aeronautical Laboratory, to furnish a basis for correct design of a hovering airplane”. The report also concluded that the specific proposed design was, “not sufficiently developed to be referred onward.” The second report involved an earlier wind tunnel test conducted in 1917 to measure drag on a free spinning eight-bladed “passive airscrew,” see Fig. 25. A number of “airscrews” were tested and the report concluded, “it appears practical to design a helicopter screw where resistance to fall shall exceed that of a disc of equal diameter.”

The end of 1919 concluded a significant chapter in naval aviation. The war was over and the value of naval aviation with airplanes that could operate from the sea was firmly established. The Navy’s aeronautics capability had been demonstrated vividly with the triumphant flight of the NC-4 across the Atlantic. As the next decade of the 20<sup>th</sup> century began, so did a new chapter in the advancement of aeronautics as the first wind tunnel of NACA became operational.

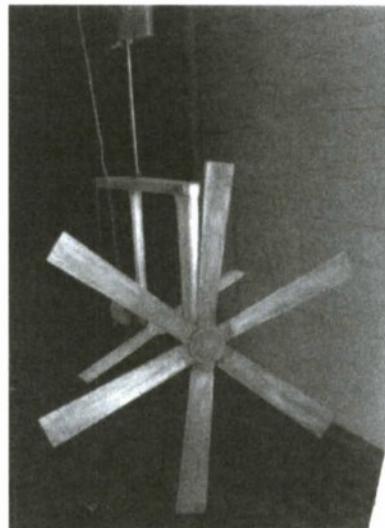
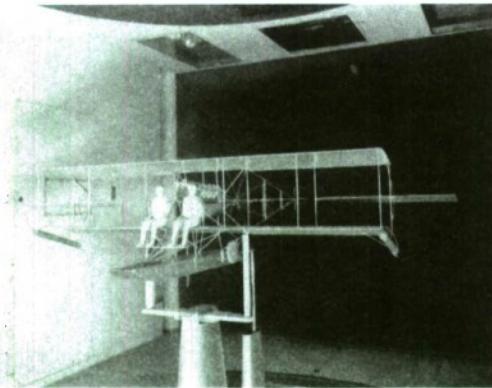


Figure 25. Tests of “passive airscrews of great resistance” were conducted in 1917 such as this 8-bladed “helicopter screw”.

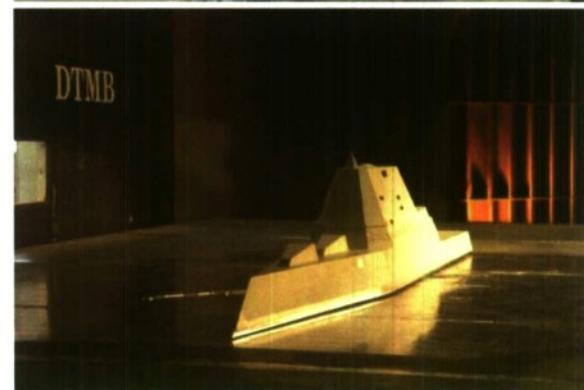
### THE LEGACY OF DAVID W. TAYLOR – 100 YEARS OF AERONAUTICS

Although David W. Taylor is remembered most for his role in naval architecture and fluid dynamics, he left an indelible mark on the development of aeronautics in the United States. Taylor, as well as his protégés Holden Richardson and Jerome Hunsaker, went on to serve important roles in the formation of and maturing of NACA. Taylor’s legacy in aeronautics spans 100 years and continues today at the David Taylor Model Basin at the Naval Surface Warfare Center, Carderock Division. The Experimental Model Basin and Aeronautics Laboratory were relocated to Carderock, Maryland beginning in 1939 with greatly improved and expanded facilities. RADM Taylor lived long enough to attend the dedication of the new model basin at Carderock bearing his name and CAPT Richardson was recalled from retirement during World War II to manage operations of the new wind tunnels at Carderock.



**Figure 26.** A model of the A-1 was tested in the Navy's 8-foot by 10-foot subsonic wind tunnel at Carderock in 1961 commemorating the 50<sup>th</sup> anniversary of naval aviation.

Beginning initially with two 8-foot by 10-foot subsonic wind tunnels, the facilities at Carderock continued to expand over the decades to include transonic, supersonic, and hypersonic wind tunnels as well as a specially designed acoustic wind tunnel with a 24-foot square anechoic test chamber. A wide variety of tests have been conducted in these facilities including aircraft store separation studies in the transonic tunnel, evaluations of advanced aircraft and rotor systems including circulation control wings and rotors, and wing-in-ground effect high-speed ships to name a few. In 1961 a wind tunnel test was conducted in the 8-foot by 10-foot wind tunnel of a model of the Navy's first seaplane, the Model A-1 to commemorate the 50<sup>th</sup> anniversary of naval aviation (Fig. 26). Beginning with the first test in David Taylor's wind tunnel in 1914, the Naval Surface Warfare Center, Carderock Division has continuously operated wind tunnels longer than any government organization in the United States (Fig. 27). Today, the Navy's large subsonic wind tunnel and anechoic flow facility at Carderock continue to be utilized to support testing of all types of vehicles and systems of interest to the Navy.



**Figure 27.** The Navy's large subsonic wind tunnel at Carderock is used today to evaluate all types of vehicles and systems of interest to the Navy.

#### ACKNOWLEDGMENTS

The authors would like to thank the museums, historians, and archivists that have assisted with all the research that went into this paper: Curtis Utz, Roy Grossnick, and the rest of the aviation staff from the Naval History and Heritage Command; CAPT Robert Rasmussen (ret) director of the National Museum of Naval Aviation; Dr. Jeremy Kinney, Roger Connor, Dr. John Anderson, and Larry Wilson from the National Air and Space Museum, and Clistine Johnson and Dana Wegner from Naval Surface Warfare Center, Carderock Division.

This page intentionally left blank

## REFERENCES

<sup>1</sup>Turnbull, A and Lord, C, *History of United States Naval Aviation*, Yale University Press, New Haven, CT, 1949.

<sup>2</sup>Grosnick, R, *United States Naval Aviation 1910-1995*, Naval Historical Center, Dept. of the Navy, Washington D.C., 1997.

<sup>3</sup>Allison, D.K., Keppel, B.G., and Nowicker, C.E., *D.W. Taylor*, United States Printing Office, Washington D.C. 1986.

<sup>4</sup>Hovgaard, W., *Biographical Memoir of David Watson Taylor 1864-1940*, presented to the Academy at the Annual Meeting, 1941. Published by the National Academy of Sciences, Washington 1941.

<sup>5</sup>Richardson, Holden, C., "Naval Development of Floats for Aircraft," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 34, Nov. 1926, pp. 15-28.

<sup>6</sup>Haas, D., Silberg, E., and Milgram, J. "Birth of U.S. Naval Aeronautical Engineering and Phenomenal Rise to Excellence" AIAA paper 2011-408, *Proceedings of the AIAA Aerospace Sciences Meeting*, Jan 4-7, 2011 Orlando, FL.

<sup>7</sup>Silberg, E., and Haas, D., "Developing the Navy's NC Flying Boats: Transforming Aeronautical Engineering for the First Transatlantic Flight" Technical abstract submitted to the AIAA Centennial of Naval Aviation Forum, 21-22 Sept 2011, Virginia Beach, VA.

<sup>8</sup>Casey, L., *Curtiss: The Hammondsport Era 1907 to 1915*, Crown Publishers, New York, NY, 1981.

<sup>9</sup>Richardson, Holden, C., "The Trend of Flying Boat Development," *Journal of the American Society of Naval Engineers*, Vol. 38, No. 2, May, 1926, pp. 231-253.

<sup>10</sup>Fresh, J., "The Aerodynamics Laboratory (The First 50 Years)," *David Taylor Model Basin Aero Report 1070*, Jan. 1964.

<sup>11</sup>McEntee, Willian, . "Navy has Largest Experimental Wind Tunnel" *Journal of the American Society of Naval Engineers*, Vol. 27, No. 2, pp 603-607, May 1916.

<sup>12</sup>Richardson, H.C., memorandum dtd. Dec. 10, 1941. H.C. Richardson Collection, Box III. Naval History and Heritage Command, Washington Navy Yard, Washington, D.C.

<sup>13</sup>Zahm, A., "Aeronautical Papers: 1885-1945 of Albert F. Zahm," Paper no. 15. Measurement of Air Velocity and Pressure (*Physical Review*, Dec. 1903), pp.113-121. The University of Notre Dame, Notre Dame, IN, 1950.

This page intentionally left blank

## REPORT DISTRIBUTION

<b>Organization</b>	<b>Name</b>	<b>Hard Copies</b>	<b>Electronic Copies</b>
Naval History Command	Curtis Utz	1	1
National Air and Space Museum	Dr. John Anderson	1	0
National Museum of Naval Aviation	Robert Rasmussen	1	1
DTIC		1	0

### NSWC Carderock Distribution

<b>Code</b>	<b>Name</b>	<b>Hard Copies</b>	<b>Electronic Copies</b>
3452	TIC	0	1
5050	T. Fu	0	1
5300	S. Ebner	1	1
5320	D. Haas	2	1
5320	E. Silberg	2	1
5320	J. Milgram	0	1
5800	R. Hurwitz	0	1

**TOTAL NUMBER OF COPIES** 9 9